Experiences of a microgrid research laboratory and lessons learned for future smart grids

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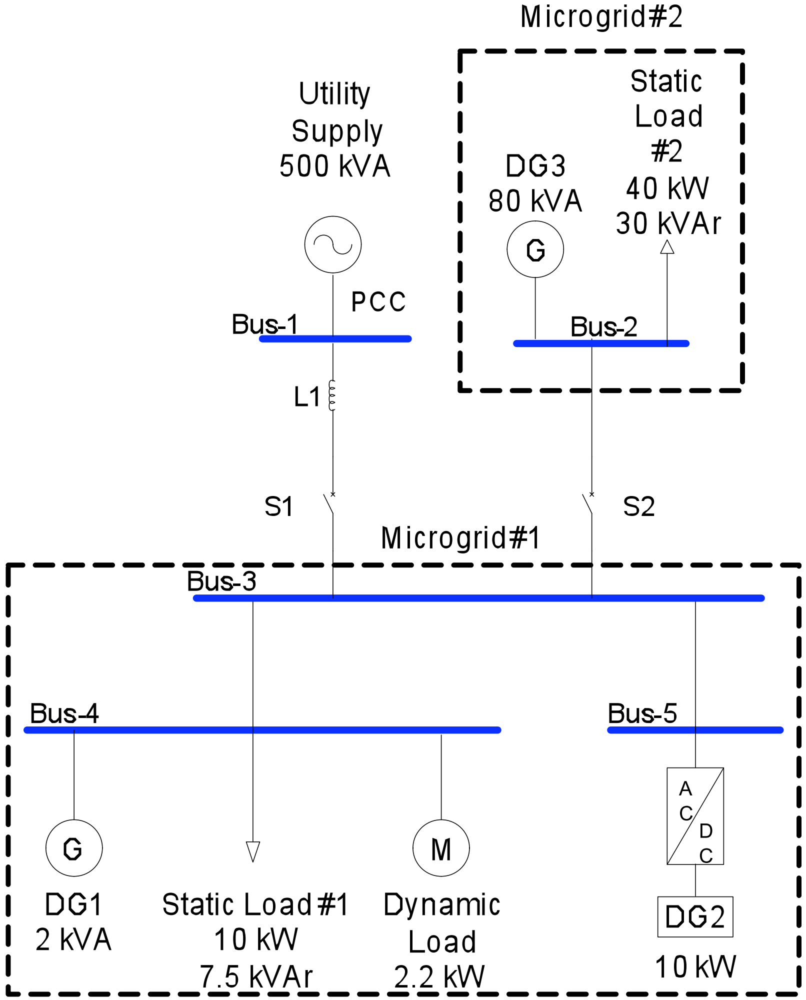
Overview

1. The D-NAP Facility
2. Power Hardware-In-The-Loop Capability
3. Case studies
   - Testing demand-side management algorithm
   - Evaluating power line carrier technologies
   - Dynamic modelling
   - Real-time grid emulator: wind turbine control design
4. Benefits of microgrid scale demonstration
5. Conclusions and lessons learned

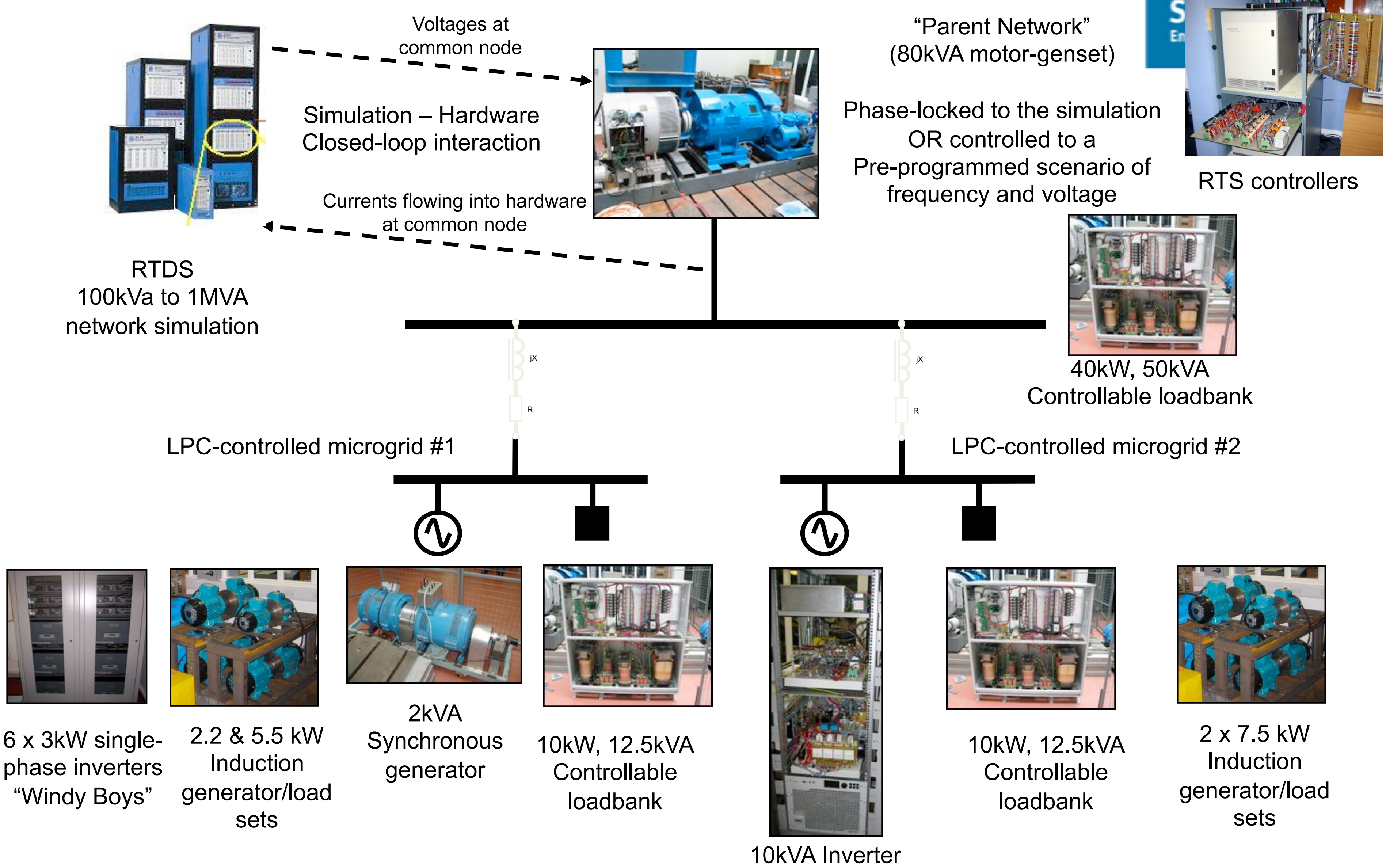
The D-NAP Facility

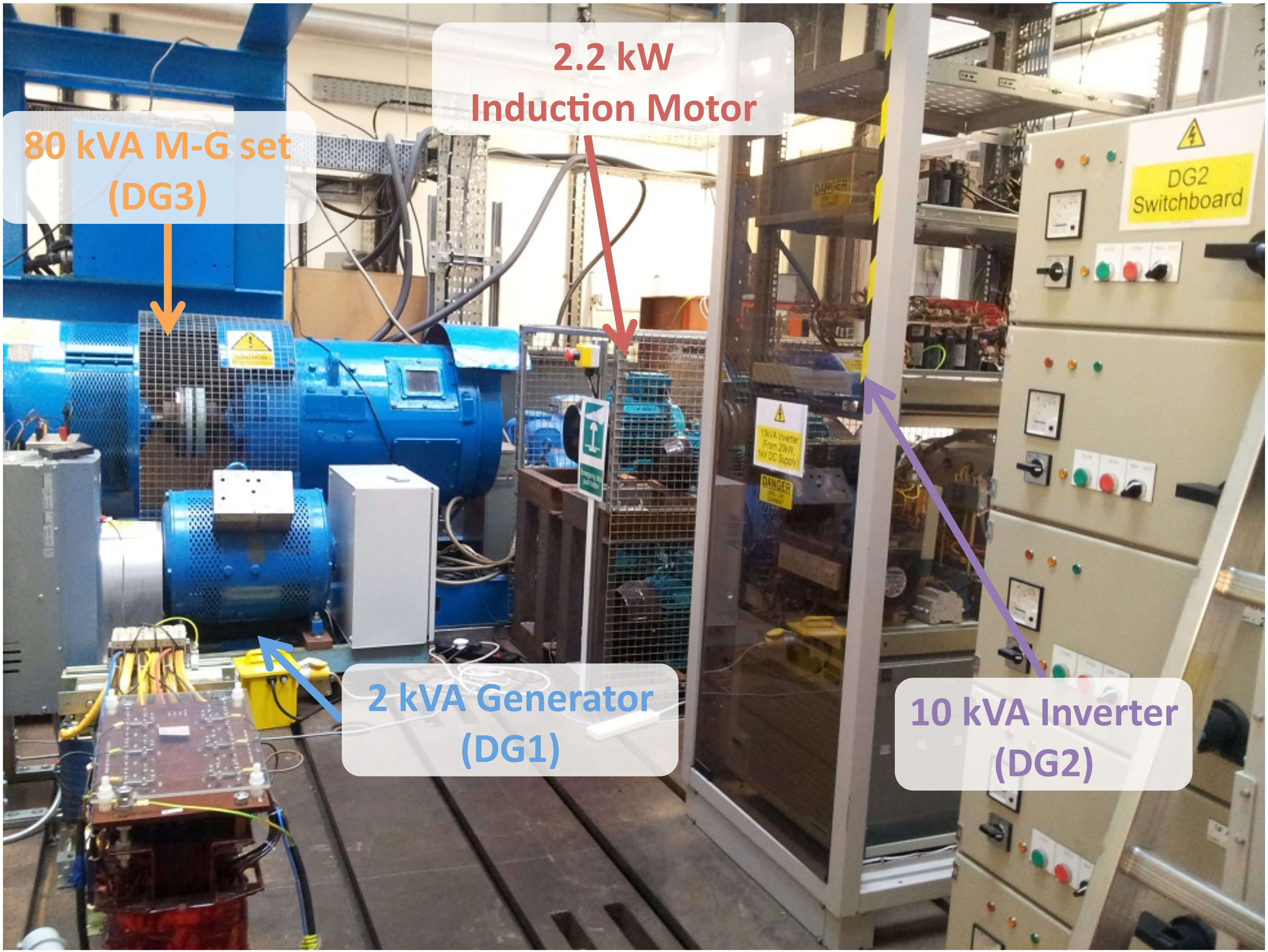
(Distribution Network, Automation and Protection)

- This is a 3-phase, 400V, 100kVA microgrid – can be split into 3 smaller microgrids
- 1.21 p.u. inductance is available to emulate stiff/ weak topologies
- Grid connection or islanded using M-G set
- M-G set connected to an RTDS to extend simulation capabilities of power systems

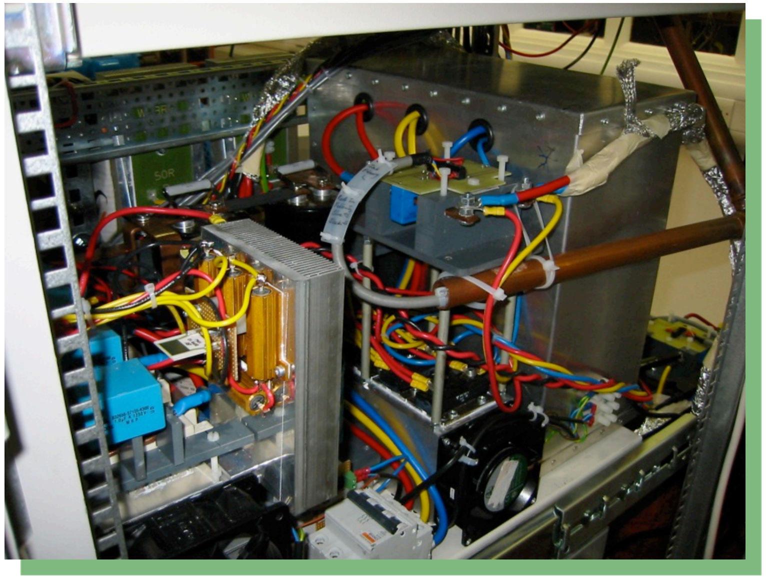


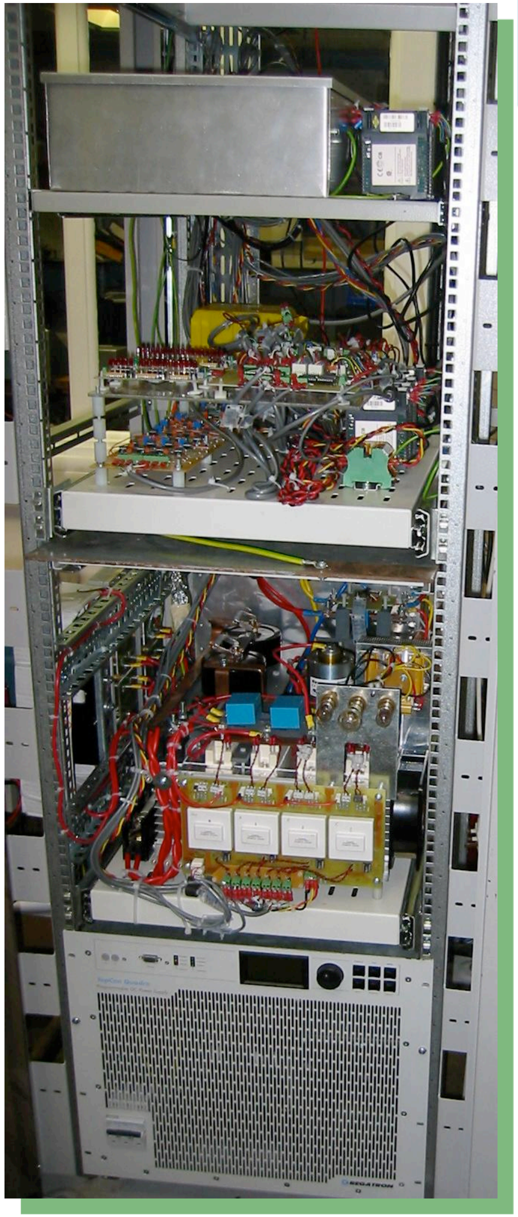
Microgrid laboratory (D-NAP)



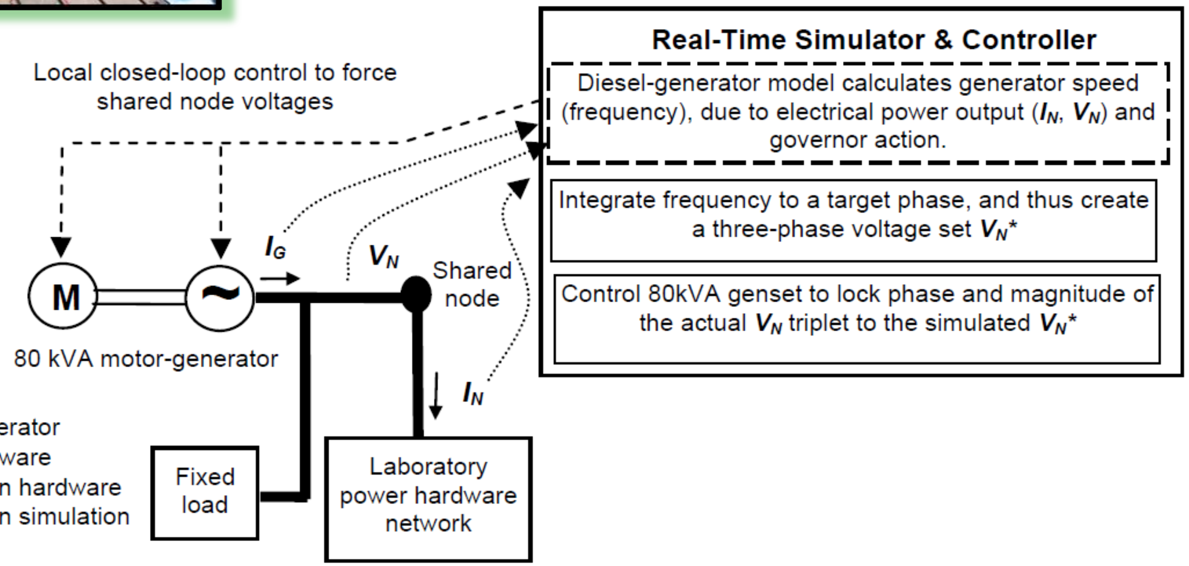

2.2 kW
Induction Motor
80 kVA M-G set
(DG3)
DG2
Switchboard
2 kVA Generator
(DG1)
10 kVA Inverter
(DG2)

10kVA inverter – Built and tested at the University of Strathclyde





RT-PHIL (Power Hardware in the Loop) Techniques and Capabilities



Key

- Physical 3-phase cable connections
- Control signals/data
- Measurements of voltages or currents
- Simulation boundary

Nomenclature

I_G Vector of 3-phase currents from 80kVA generator
I_N Vector of 3-phase currents flowing into hardware
V_N Vector of 3-phase voltages at shared node in hardware
V_N^* Vector of 3-phase voltages at shared node in simulation

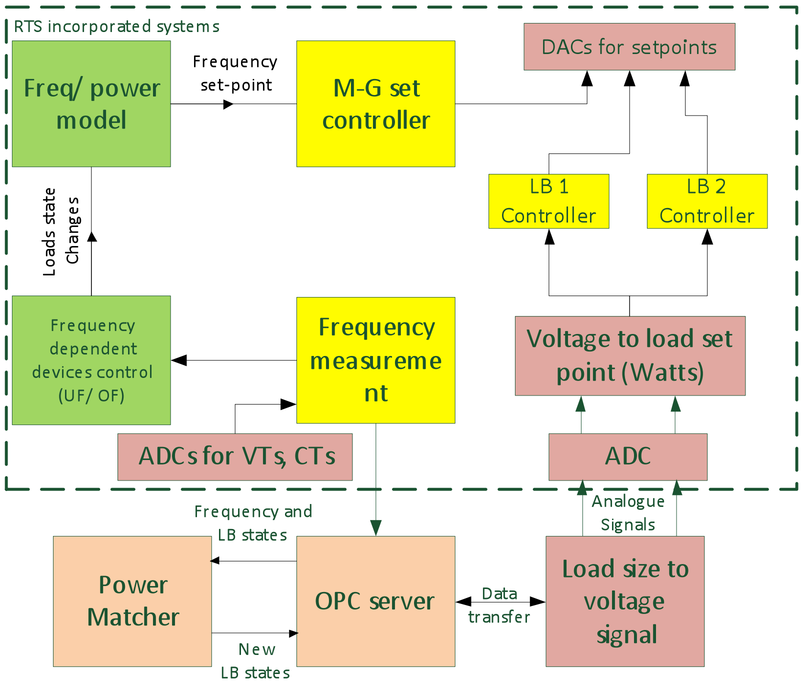
CASE STUDIES

Fast demand response in support of the active distribution network

– *with TNO Netherlands*

- **Observe demand response's potential to contribute to frequency control of the power system**

- Test this potential against a real frequency excursion event using an integrated laboratory test environment

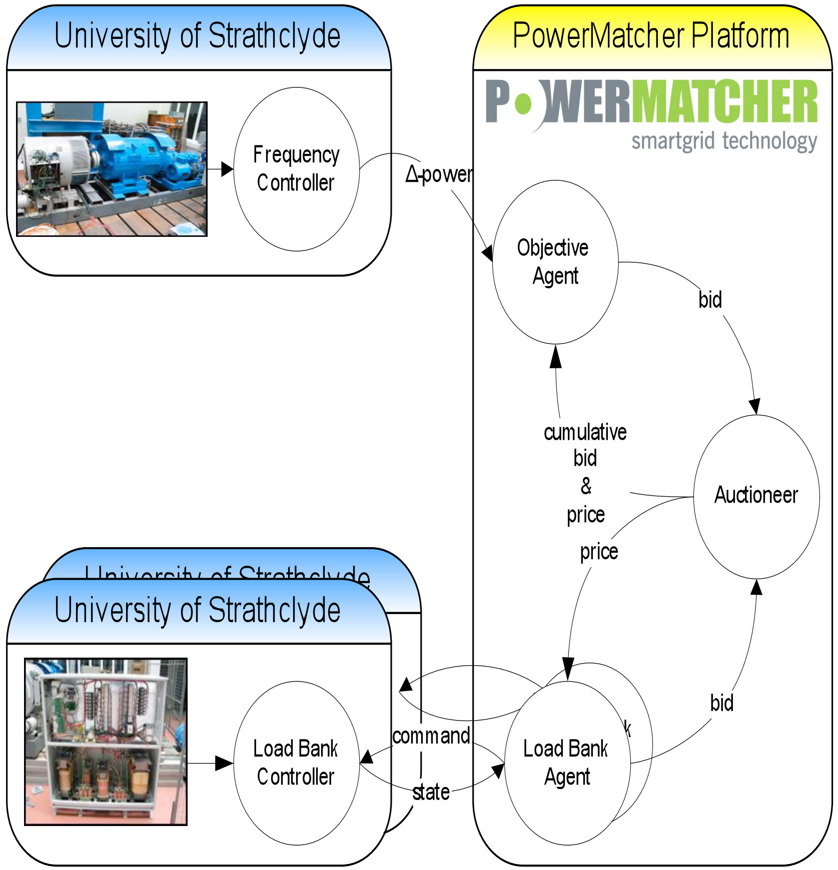


PowerMatcher as part of RT-PHIL

- **PowerMatcher integrated within D-NAP laboratory to control loads as part of a real-time power hardware-in-the-loop experiment (RT-PHIL)**

- Simulation based on a real event – 2008 UK frequency excursion

- Real-time market based control using the PowerMatcher



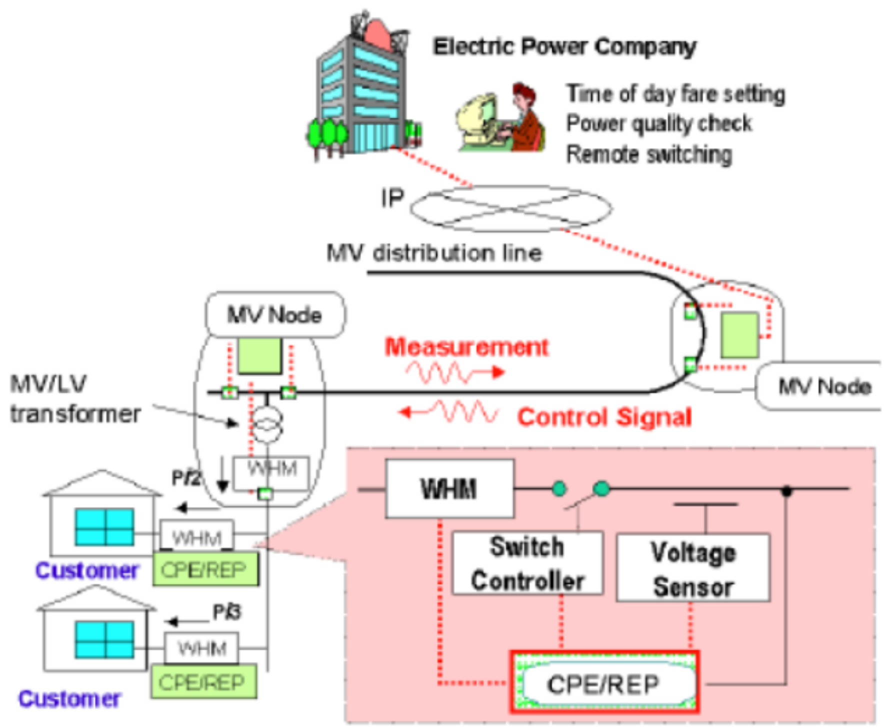
Evaluating **smart grid communication** in an industrial microgrid environment

- *with University of Udine*

- **Characterisation of power line carrier (PLC) channels within a controllable, electrically noisy, LV network**

- Investigation of the possibility of using PLC in a laboratory for control

- Identification of noise sources for deployment of PLC for smart grid technologies



Dynamic performance of a low voltage microgrid with droop controlled distributed generation

- *with Aristotle University of Thessaloniki*

- Using experimental measurements of a microgrid’s (MG) characteristics to validate a dynamic black-box model
- **Focusing on small-signal dynamics (challenging task when large number of ac/dc – dc/ac interfaces are involved**
- Investigate the interactions between rotating and inverter interfaced DG units
- MG examined in grid-connected and islanded mode

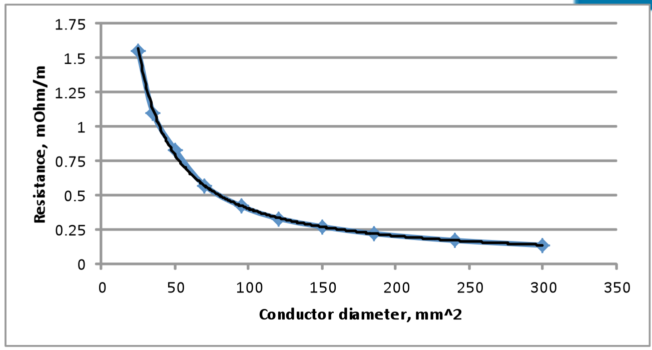
Summary of microgrid projects

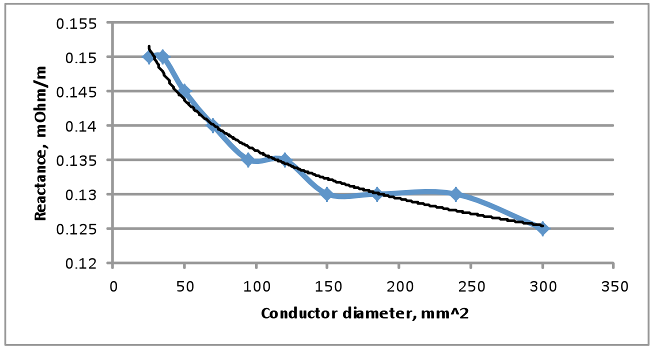
- **DERRI Transnational Access**
  - DISCOSE (*Testing PowerMatcher in RT-PHII environment*)
  - POLSAR (*Investigating PLC in a microgrid*)
  - MoDERN and MoreModern (*Dynamic modelling in a microgrid*)
  - DERManagement (New energy management technology)
  - PV-APLC (*detecting and adjusting unbalance and harmonics*)
- **EURAMET** (*state estimation modelling and validation*)

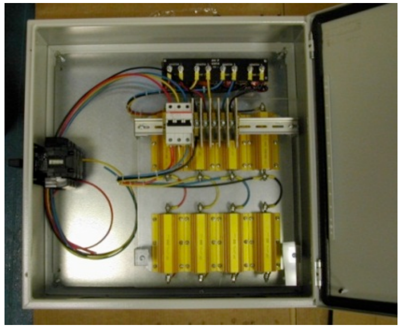
SOME LESSONS LEARNED AND POSSIBLE SOLUTIONS

Low Voltage Branch Grid Impedance

- The impedances of the grid branches at low voltage level very often are not well known.
- For this reason the grid models at low voltage level are afflicted by an important uncertainty.
- **Measurements in the lab and estimations, based on values available in literature, have been done in order to better evaluate these impedances.**
- **It is still open the problem to find an optimal way to evaluate the grid impedances on the real field.**







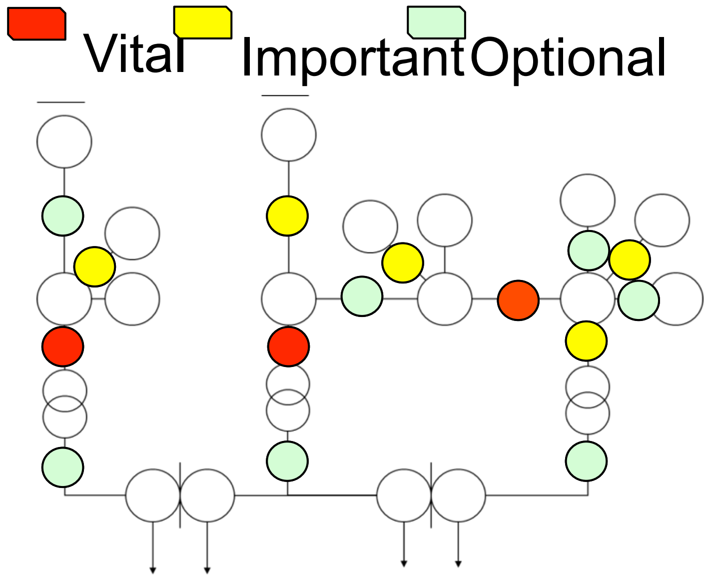
Sensitivity Analysis

- Distribution networks present a large number of nodal points.

- **The installation of monitoring and metering is expensive particularly at MV and LV where the installation of new VTs and CTs may be necessary.**

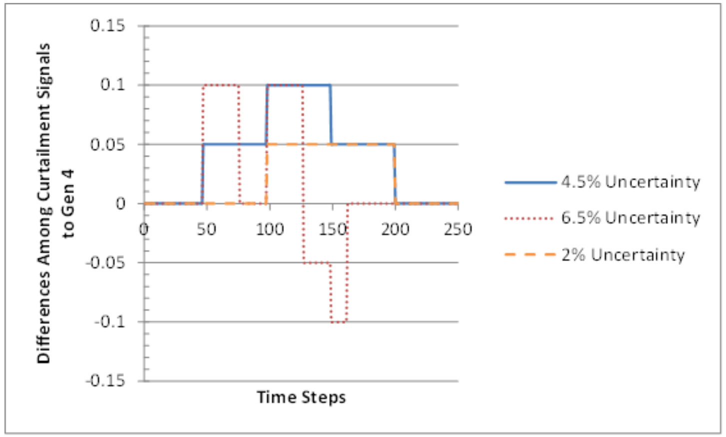
- **It is not possible to measure at every node and branch.**

- **It is crucial identifying a strategy to optimize the location, the number of the measurement point is important for effective network control; in order to do this, a technique based on sensitivity analysis has been developed successfully.**



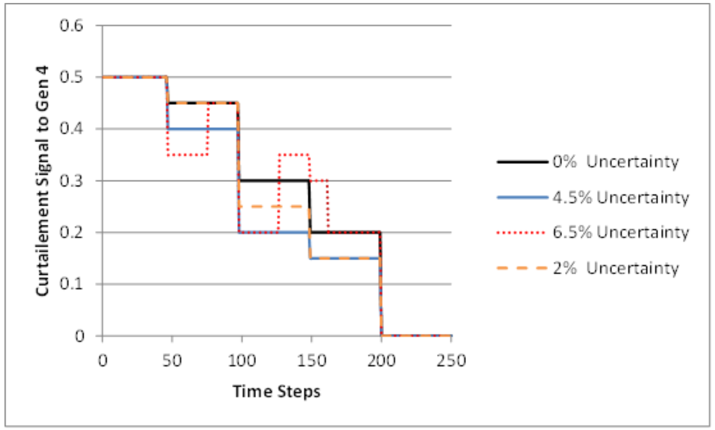
Active Network Management

- **A critical concern is the robustness of online and automatic active network management (ANM) algorithms/schemes**.

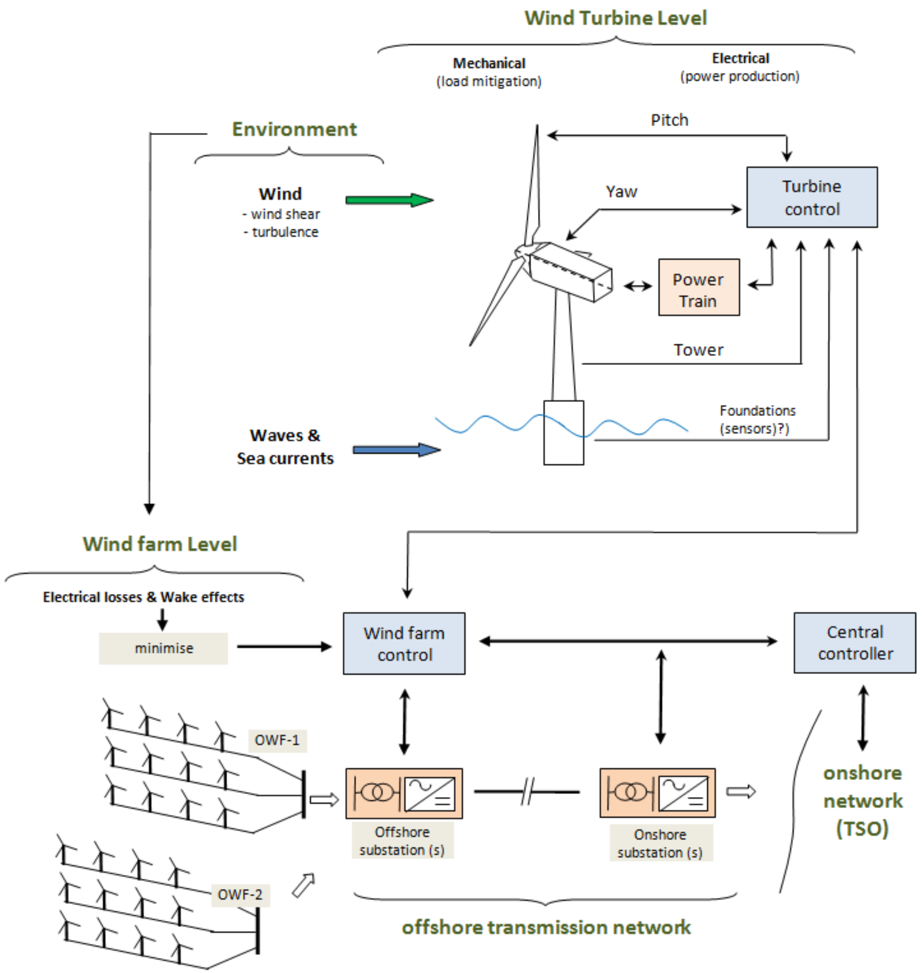


- The ANM scheme's functionality depends on convergence to a solution when faced with uncertainty and its **reliability can be reduced by data skew and errors**.

- **It is important to assess ANM performances when subjected to different levels of data uncertainty and verify the introduction of a state estimator (SE) in the ANM architecture to mitigate the data uncertainty effects on the control action.**



RT-Grid Emulator for wind turbine control design purpose (in its early stages)



Lack of facilities with capacity to test in a holistic manner full-scale grid-connected wind turbines in a controlled environment

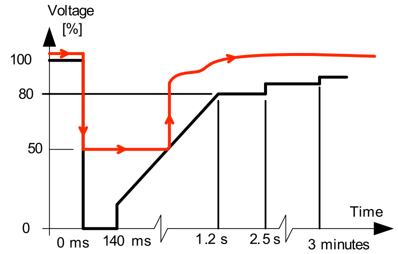
Some have the turbine but not the grid

Some have the generator and grid (LV) – but not the turbine

Objectives

1. Design a Grid Emulator test rig (structure and components) that will allow to perform endurance testing and power quality validation for wind turbines based on the requirements of:

   - International Grid Codes
   - Standard (e.g. IEC, etc.)
   - Guidelines (e.g. IEEE, GL, etc.)



GB FRT requirement

2. Turbine control performance assessment (may assist understanding and addressing scalability issues)

3. Portability ('bring' the grid where needed!)

RT-Grid Emulator at NAREC

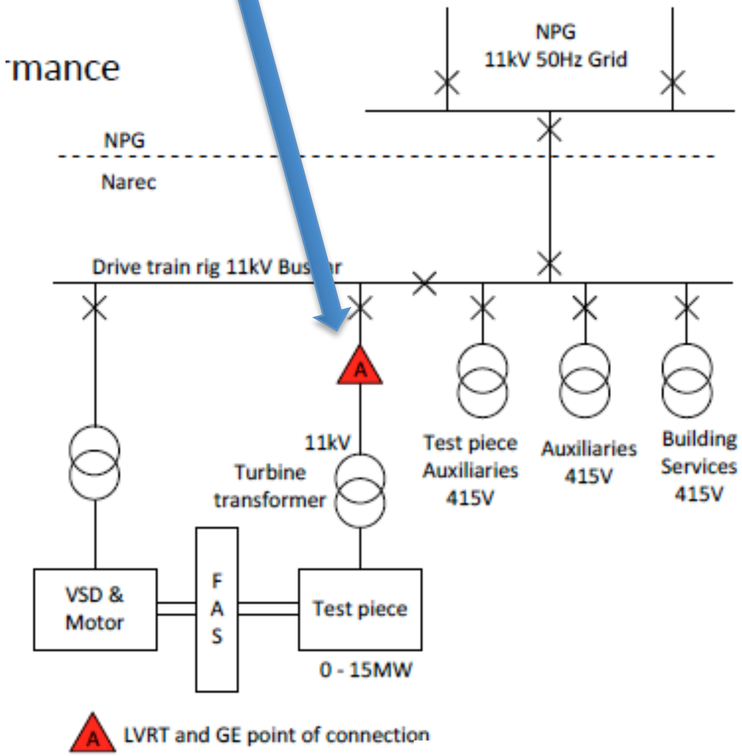
Specifications:

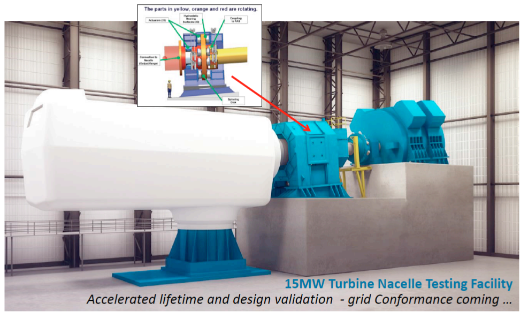
- Rated at 10MW, 11kV both ends
- Ability to perform electrical Hardware in the loop operation

Capabilities:

- Asymmetrical/unbalanced condition
- Grid fault level condition
- Harmonic distortion conditions

Will require power electronic interfaces for power conditioning/





Benefits to using a Microgrid test bed

- Flexible configurations in a fully instrumented network
- No customers to accidently disconnect (saves $)
- Can run devices through scenarios rarely observed on the public grid, e.g. frequency dips.
- Devices can be installed within a controlled environment and constantly monitored
- New technologies can be evaluated for multiple stakeholders

Conclusions

- Microgrid test labs are capable of more than just demonstrating microgrid technologies
- Useful platforms for validation and prototyping of novel technologies
- Can be a route for smart grid technologies into private microgrids and the public grid.

University of
Strathclyde
Glasgow